Long-term field experiments in water quality

The Swedish University of Agricultural Sciences

Department of Soil and Environment

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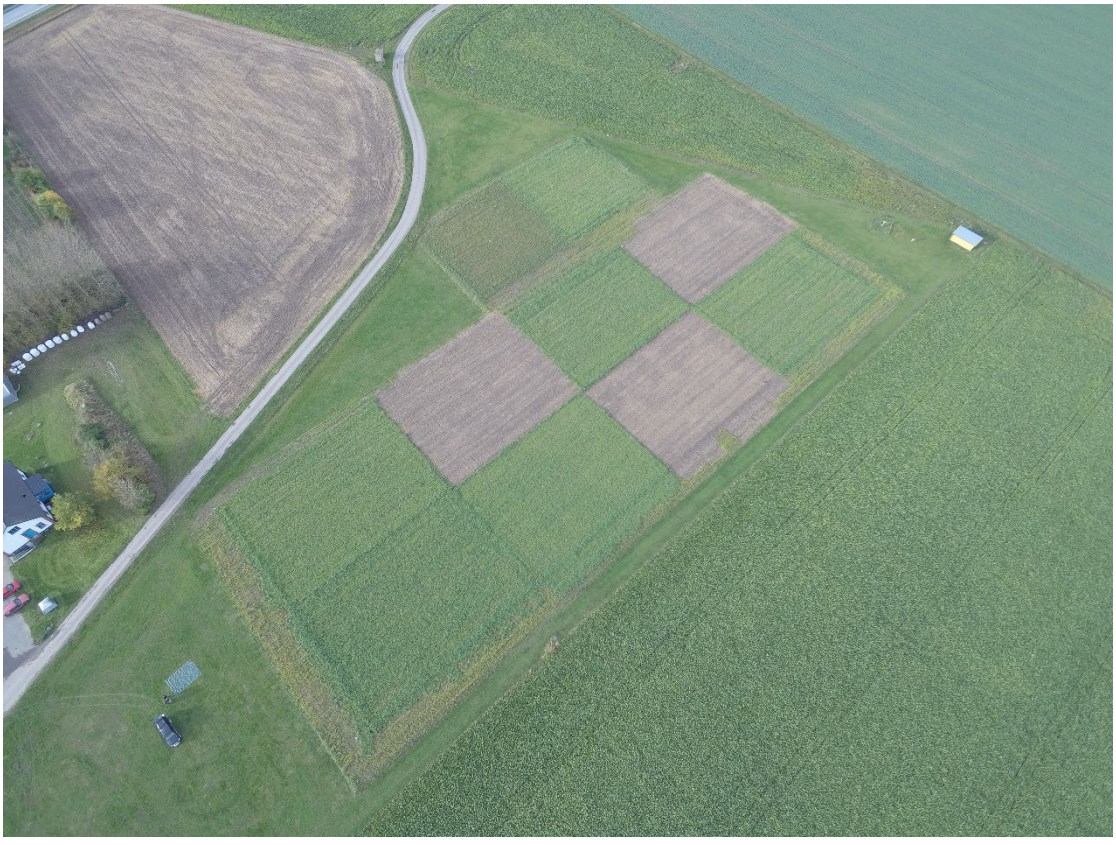

Field experiment at Lönnstorp research station (Photo: Ryan Davidson).

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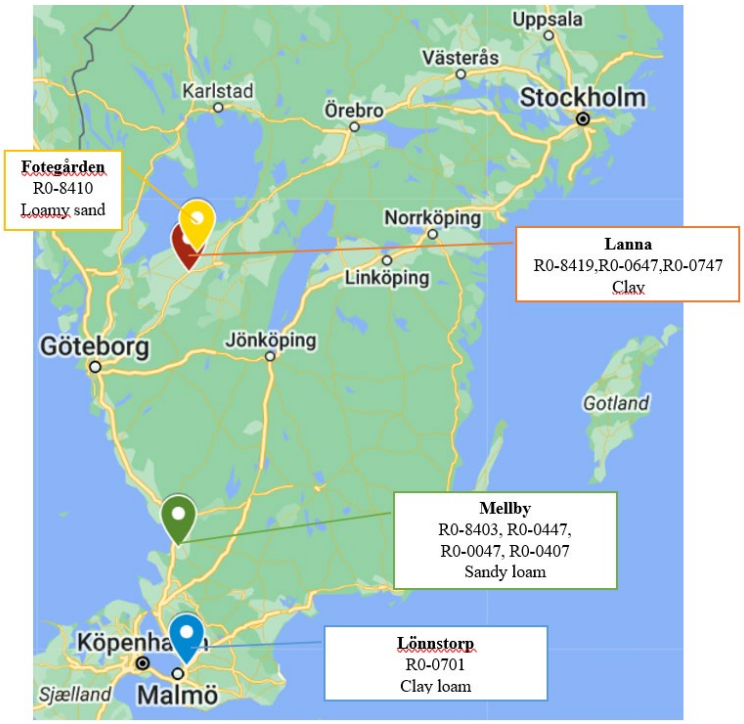
1. Introduction

This is an overview of the 9 long-term field experiments in water quality managed by the Department of Soil and Environment at the Swedish University of Agricultural Sciences. All 9 experiments are situated in special facilities at four sites, which are constructed for measurements of drainage flow and transport of nutrients or other compounds. The studies evaluate how nutrient management, crop sequence and other practices affect nutrient leaching. This include tillage strategies, applications of animal manure and cover crops in either or both conventional and organic cropping systems.

Researchers and students are welcome to utilize the experiments, the collected data and the archived samples. See section 8 for information about how to obtain access.

1.1 Experimental method

The four experimental sites represent different climates and different soils (Appendix, Table 9 and 10). The experiments are constructed with separately tile-drained plots (at about 90 cm depth) for leaching measurements (see picture). The plots are large, ranging from 840 m^2 to 4000 m^2 (Appendix, Table 9 and 10). Water flow is measured continuously (tipping-buckets or V-notch) and recorded with data-loggers. The tile-drainage flow normally occurs from October to May. Since 1989, automatic flow-proportional water sampling is used, with collection of composite samples every fortnight. The analysis program originally included nitrate nitrogen (NO_3-N), total nitrogen (Tot-N), potassium (K), phosphate phosphorus (PO_4-P) and total phosphorus (Tot-P). There is now some variation over the years and between sites. Measurements also include soil samples for mineral nitrogen determination down to a depth of 90 cm. Biomass of harvested crops and cover crops are sampled and its content of nitrogen (N), phosphorus (P), potassium (K) for harvests and N and carbon (C) for cover crops, are analysed. Approx. every sixth year soil samples for basic soil chemical properties (total carbon, total phosphorus, total nitrogen etc.) are collected. Samples of grains and soil are stored in an archive.



Location of the four sites with long-term field experiments in water quality.

All management practices, observations, soil and crop data, and water flow and water quality data from the experiments are documented and stored in databases (Microsoft Access) (Appendix, Table 11). The databases are stored on the SLU data server and back-up copies of the server are made on a regular basis.

Two of the sites, Mellby and Lanna, also have additional tile-drained plots. The infrastructure for long-term studies thereby constitutes a platform, which also generates coordination benefits for other projects. Numerous of experiments on adjacent plots has been performed during the years.

1.2 Historical funding

The first two decades of the water quality long-term experiments had additional funding from other sources, mainly from the Swedish Board of Agriculture. This was during a period where there was an urgent need of knowledge about impact of agriculture on water quality in Sweden and how to mitigate nitrogen, and later on, phosphorus losses.

1.3 Impact on society and policy

The experiments have contributed with substantial knowledge about the impact of agriculture on water quality. Although there are only few sites, they have provided insight into how different soil types and climates affect leaching losses in combination with different crops and management practices. An important finding was that there are no fundamental differences in leaching losses from organic farming compared to conventional farming. This was controversial in 1990s, but it contributed to the focus on specific measures for improving both systems, implemented in advisory programs for farmers. Effects of tillage practices, cover cropping, crop rotation, mineral fertilizers and animal manures have been investigated in the long-term experiments, and together with other studies they contributed with knowledge to develop decision support tools, legislation (Nitrates directive, Nitrates (europa.eu)) and subsidy systems within CAP (Common agricultural policy (europa.eu)). The tool VERA was developed based on empirical data and is used on farms for estimating effects of crop rotation, tillage and fertilization on N leaching (www.greppa.nu/vara-tjanster/rakna-sjalv/vera). The cover crop experiments were important to formulate stipulations for a subsidy, which was introduced in 1995, and the experiments were also important for assessing potential effects on carbon storage. In 2023, a new subsidy for cover crops with focus on carbon farming was lounged (www.jordbruksverket.se).

Separate tile-drained plots (left), led to an underground measuring station (middle) with tipping-buckets and flow-proportional water sampling (right). Composite water samples in bottles are emptied every other week and sent for analysis.

2. Nutrient leaching from a cereal crop rotation with pig slurry and cover crops, R0-8403

This experiment started in 1984 with the overall aim to evaluate effects of pig manure, applied in spring or autumn and at different rates, on N, P and K leaching. Animal production and potato crops dominated this region, just beside the coast. Soon also cover crops were introduced in the experiment, which proved to be very successful for improving the water quality. This is the oldest experiment with continuous use of cover crops in Sweden and has been used for assessment of long-term effects of cover crops and manure applications on N and P leaching and on C stocks. Today the core design of the experiment remains, but treatments have been changed from 2010 in order to have replicates (Table 1). Excluded treatments were autumn application and high doses of pig slurry, which has delivered valuable information to earlier knowledge gaps.

Spring cereals are grown almost every year and the straw is removed from the field. Perennial ryegrass (*Lolium perenne*) is used as a cover crop, undersown in the main crop in spring. Stubble cultivation and moldboard ploughing are practiced, in autumn for plots without cover crops and in spring for cover crop treatments. Mineral fertilizer or pig slurry is combined with cover crop. Pig slurry is applied according to a P dose of 20 kg/ha and complemented with mineral N (assuming 90 % efficiency of ammonium in slurry).

Water flow is registered and flow-proportional water samples are analysed for Tot-N, Tot-P, PO_4-P and K. Harvested grain and straw is analysed for N, P and K and then archived. The soil is analysed for mineral N three times per year and samples for basic soil chemical properties are taken with six years interval (archived). Cover crop biomass and its N and C content is determined in late autumn.

Staff at Hushållningssällskapet Halland perform the experimental work.

Table 1. Treatments in the R0-8403 experiment, in crop rotation with spring cereals and cover crops of perennial ryegrass, since 2010

Treat-ment	Plot no	Cover crop	Stubble cultivation	Tillage	Fertilizer, kg/ha			Pig slurry*
					N	**P**	**K**	
A	7	No	1-15 Sep	Nov-Dec	0	0	60	0
B	5	Yes	Feb-Mar	Feb-Mar	0	0	60	0
C	2, 11, 12	No	1-15 Sep	Nov-Dec	90/110	15	60	0
D	10, 13, 14	Yes	Feb-Mar	Feb-Mar	90/110	15	60	0
E	1, 8, 9	No	1-15 Sep	Nov-Dec	90/110-0.9 *manureNH_4	0	30	20 kg P/ha
F	3, 4, 6	Yes	Feb-Mar	Feb-Mar	90/110-0.9 *manureNH_4	0	30	20 kg P/ha

3. Nutrient leaching from a cereal crop rotation with cover crops, autumn and spring tillage, R0-8410

The experiment R0-8410 started in 1993 with the aim to measure how different crop management influences the leaching losses of N, P and K. The different treatments were pig manure, stubble cultivation, autumn and spring tillage, and cover crops. From 2007, the experiment has three treatments, which compares autumn tillage in October-November, with spring tillage in March-April, with and without undersown perennial ryegrass (*Lolium perenne*) cover crops.

The main crops and crop management follow the management of the farm Fotegården where the experiment is located. The crop rotation is mainly spring cereals, but potatoes are grown some years. Biomass samples of cover crops and weeds is collected every autumn with analyses of N and C. Samples for soil mineral N have been taken most years at harvest, late autumn and in spring. Yields of main crop are determined and analysed for N, P and K, and samples of grain are archived. Samples for basic soil chemical properties are taken with six years interval (archived). Water flow is registered and flow-proportional water samples are analysed for Tot-N and Tot-P. Earlier years also NO_3-N, PO_4-P and K was analysed.

Staff at Lanna Research Station, SLU, perform the experimental work.

Table 2. Treatments in the R0-8410 experiment from 2007

Treatment	Plot no	Autumn/spring tillage	Cover crop
A	4 & 8	Autumn	No
B	2, 3 & 5	Spring	No
C	1, 6 & 7	Spring	Yes, Perennial ryegrass

Table 3. Treatments in the R0-8410 experiment in 1993-2006

Treatment	Plot no	Autumn/spring tillage	Stubble cultivation	Pig manure	Cover crop
A	1	Autumn	Autumn	No	No
B	2	Autumn	Autumn	Yes	No
C	3	Autumn		No	Yes
D	4	Autumn		Yes	Yes
E	5	Spring	Spring	No	No
F	6	Spring	Spring	Yes	No
G	7	Spring	Spring	No	Yes
H	8	Spring	Spring	Yes	Yes

4. Nutrient leaching - Strategies for cover crops in southern Sweden, R0-0701

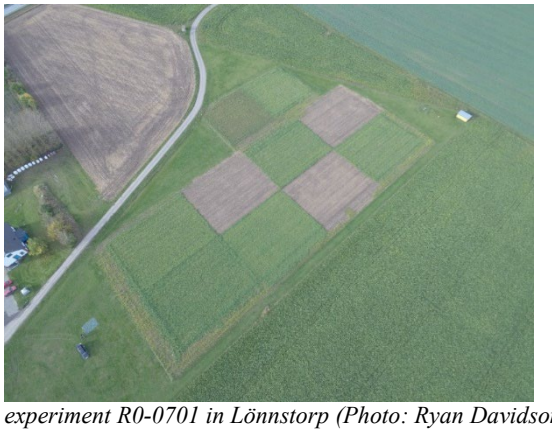
The experiment R0-0701 on Lönnstorp Research station, SLU, has a focus on vegetation cover of the soil in autumn and cover crops in a southern Sweden (Skåne) context, but has no fixed set up. The treatments has changed since the start 1993 in order to follow the development of agriculture and address current crop management issues. There has been a rotation of treatments over the plots in order to avoid build-up of differences between individual plots. By this, the long-term idea of this field is to maintain a place for testing upcoming cover crop concepts continuously.

Biomass samples of cover crops and weeds are collected every autumn with analyses of N and C. Samples for soil mineral N is taken at harvest, late autumn and in spring. Yields of main crop are determined every year with analyses of N, P and K and samples of grain are archived. Samples for basic soil chemical properties are taken with six years interval (archived). Water flow is registered and flow-proportional water samples are analysed for Tot-N and Tot-P. Earlier years also NO_3-N, PO_4-P and K was analysed.

Staff at Lönnstorp Research Station, SLU, perform the experimental work.

Table 4. Crop rotations and cover crops in the R0-0701 experiment

Year	Treatment	Plot no	Cover crop	Tillage
2022-2025	A	2, 4 & 7	No	Autumn
	B	3, 6 & 8	Yes	Autumn
	C	1, 5, 9 & 10	Yes	No-till
2018-2021	A	In rotation	No	Autumn
	B	In rotation	Phacelia+red clover	Spring
	C	In rotation	Phacelia+ryegrass	Spring
	D	10	Oats	Spring
2012-2017	A	In rotation	No	Autumn
	B	In rotation	Oilseed radish	Spring
	C	In rotation	Hairy vetch, Buckwheat etc.	Spring
	D	10	Oats	Spring
2008-2010	Energy hemp (2 plots) Energy beets (2 plots) Maize (2 plots) Winter wheat with cover crop (2 plots)			
1993-2007	Two winter wheat crop rotations with 80% winter covered soil including autumn sown crops, sugar beets and fallow.			



The experiment R0-0701 in Lönnstorp (Photo: Ryan Davidson).

5. Nutrient leaching from conventional tillage, no-till and permanent grass, R0-8419

The experiment R0-8419 started in 1993 with focus on different soil management systems. Between 2008 and 2018, reduced tillage was compared with moldboard ploughing, with three replicates of each treatment. In 2019, the reduced tillage treatment was changed to no-till treatment, both with the same cereal based crop rotation with cover crops. Management practices are considered together with a local farmer with interest in and experience of no-till systems and conservation agriculture. Since the experiment has large plots (40*100m), individual treatment timing can be adapted for the two systems, which is very valuable for this type of experiment.

Plot 7 has been under permanent grass since the start in 1993. The grass is cut once a season and the biomass determined. This type of areas, representing land use change from arable land to set-aside land, are very interesting for producing reference values for what is reachable targets for water quality.

Samples for soil mineral N is taken at harvest, late autumn and in spring. Yields of main crop are determined every year with analyses of N, P and K and samples of grain are archived. Samples for basic soil chemical properties are taken with six years interval (archived). Water flow is registered and flow-proportional water samples are analysed for Tot-N, Tot-P, PO_4-P, turbidity and K.

Staff at Lanna Research Station, SLU, perform the experimental work.

Table 5. Treatments included in the R0-8419 experiment.

Year	Treatment	Plot no	Tillage
2019 -	A	2, 3 & 6	Conventional moldboard plough
	B	1, 4 & 5	No-till
	C	7	Permanent grass since 1993
2008-2018	A	2, 3 & 6	Conventional moldboard plough
	B	1, 4 & 5	Reduced tillage
	C	7	Permanent grass since 1993
2007-2008	Green and stubble fallow		
2000-2006	Tillage times in winter wheat cropping system		
1993-1999	Cover crops and soil management systems		

6. Nutrient leaching from organic cropping systems with and without livestock, Lanna and Mellby, R0-0647, R0-0747, R0-0047, R0-0447

A series of experiments with organic cropping were started in 1998 with the aim to study realistic crop rotations for systems with and without livestock, in this case a system with dairy production and a system with crop production. One of each system were placed at Lanna and at Mellby, respectively. The systems were adapted to follow the principles for organic farming and regulations for the Swedish certification system for organic farming (KRAV), and this was done in collaboration with stakeholders. The amount of cow manure (applied as liquid manure) was adapted to represent the amount of cows on a farm with animal feed self-sufficiency. Even though organic farming has developed towards increased intensity with import of feed or manure from conventional farms, this is still in the core idea of the design. This implies that the amount of manure used corresponds to 0.7 dairy cows/ha. In the crop production systems, N-fixing crops contribute with N, but also biofertilizers are used, which provide N, P and K.

These experiments generated considerable knowledge about nutrient dynamics and losses in organic cropping systems and also about how to manage grass/clover leys and green manure crops in order to reduce leaching risks, for example with timing of harvests and time of incorporation. From 2020, we introduced a somewhat new design in order to investigate strategies for weed control. This is a challenge in organic crop production, where intensive mechanical treatment of weeds often increase the risk of N leaching. Therefore, strategies with row hoeing and cover crops for suppression of weeds is highly interesting. Two strategies are studied, one with high tillage intensity and one where row cultivation and cover crops (where possible) is the main method for weed control. The leys will also be an important component for weed suppression although this is the same for both strategies.

During the years, samples for soil mineral N has been taken at different times but in the present strategy no mineral N is determined. Yields of main crop, including leys, are determined every year with analyses of N, P and K and samples of grain are archived. Samples for basic soil chemical properties are taken with six years interval (archived). Water flow is registered and flow-proportional water samples are analysed for Tot-N, Tot-P, NO_3-N and K.

Two plots at Mellby, next to R0-0047, have been under permanent grass since 2007. The grass is cut once a season and the biomass determined. This type of areas, representing land use change from arable land to set-aside land, are very interesting for producing reference values for what is reachable targets for water quality.

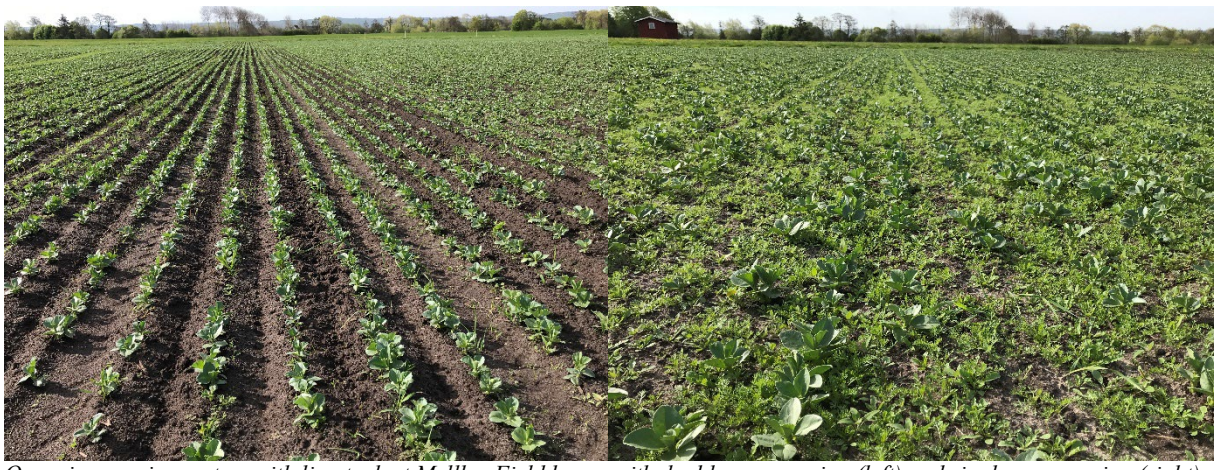
Staff at Lanna Research Station, SLU, perform the experimental work at Lanna and staff at Hushållningssällskapet Halland at Mellby.

Table 6. Crop rotation and treatments in the organic cropping system experiments since 2020

Crop rotation	
With livestock	*Without livestock*
Oats with undersown ley	Oats with undersown ley
Ley I	Red clover seed
Ley II	Green manure
Oil rape seed	Oil rape seed
Winter wheat	Winter wheat
Field bean	Field bean
Treatment A	Strategy for weeds with leys and repeated stubble cultivation in autumn
Treatment B	Strategy for weeds with leys, double row spacing and row cultivation during season

Table 7. Main components of crop rotation and treatments in the organic cropping system experiments, 1998-2018

Crop rotation at Lanna		Crop rotation at Mellby	
With livestock	*Without livestock*	*With livestock*	*Without livestock*
Whole grain silage with undersown ley	Oats with undersown ley	Whole grain silage with undersown ley	Oats with undersown ley
Ley I	Ley for green manure	Ley I	Ley for green manure
Ley II	Oats	Ley II	Spring wheat
Oats	Winter wheat with undersown ley	Ley III	Winter rye with undersown ley
Winter wheat	Ley for green manure	Oil rape seed+cover crop	Ley for green manure
Field bean	Spring wheat	Barley	Oil rape seed+cover crop
	Field bean		



Organic cropping system with livestock at Mellby. Field beans with double row spacing (left) and single row spacing (right) (Photo: Lisbet Norberg)

7. Nutrient leaching from conventional cropping system with livestock, Mellby, R0-0407

In 2020, a former long-term experiment at Mellby (N-efficient soil management systems, R2-8407) was changed in order to become a conventional reference to the organic cropping system with animals. The systems and treatments can be directly comparable. This experiment follows the same management practices as the organic experiments at Mellby (R0-0047 and R0-0447). However, mineral fertilizer and chemical pesticide control can be used.

The experiment was earlier organized under Soil management and focused on increased N use efficiency in different soil management systems. This former experiment had a crop rotation where there was not supposed to be large legacy effects on individual plots.

Table 8. Crop rotation and treatments in the conventional cropping system experiment since 2020

Cropping system	
With livestock	
Oats with undersown ley	
Ley I	
Ley II	
Oil rape seed	
Winter wheat	
Field bean	
Treatment A	Strategy for weeds with leys and repeated stubble cultivation in autumn
Treatment B	Strategy for weeds with leys, double row spacing and row cultivation during season

8. Access to data and material from the long-term experiments in water quality

Researchers are allowed to use data and material from the long-term experiments, as long as the proposed activity does not cause large difficulties for SLU staff or diminish the future value of the field experiments. If the proposed activity entails more than a moderate cost to the Institution of Soil and Environment, the user will be expected to cover it. The long-term field experiments can be used for commercial research, but special legal contracts might be required.

Data and materials from the long-term field experiments are not allowed to be delivered to any third party without written permission from the person responsible for the field experiment. The user's right to use data that they neither collected nor financed to collection expires four years after the signing of the application form. After this time, the user has no right to keep any copies of the provided data. A new application is required for continued use.

Procedure to access long-term experiments in water quality

1. Users should make contact with the person responsible for the long-term experiments, via email at the following address: helena.aronsson@slu.se, lisbet.norberg@slu.se
2. Needs and resources are discussed. In most cases, a cooperation partner from the Department of Soil and Environment is selected, either the person responsible for the field experiments or someone with other relevant expertise. The conditions for cooperation are agreed upon. These can include future co-authorship of papers and the covering of costs.
3. A formal application is submitted to the person responsible for the field experiments. A copy must also be send to the coordinator of SLUs long-term experiments
4. The application is handled by the person responsible for the field experiment.
5. The user gets access to data and material when the application is granted.
6. The person responsible for the field experiments are responsible for providing information about experimental design, sampling techniques, and other scientific and practical issues.
7. Before any results are published, the selected cooperation partner at SLU should have the opportunity to review the manuscript.
8. All published material should be sent to the person responsible for the field experiments, for archiving.

Publications list

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Appendix

Table 9. Overwiew of selected metadata for the R0 experiments with separately tile-drained plots

Experiment serie	Experiment number	Site name	Start year	Soil type	Plot size (m)	No. of plots	Spacing between tiles (m)	Depth of tiles (m)	Treatment replicates	Set crop rotation	Types of fertilizer/ amendments	Cover crops	Autumn/spring tillage	Permanent grass
R0-8403	N-026-1982	Mellby	1984	Sandy loam	40x40	14	6	0.9-1	1-3	Yes	NPK, Pig slurry	Yes	Autumn/spring	
R0-8410	RX-201-1992	Fotegården	1993	Loamy sand	28x30	8	14	0.9-1	2-3	Yes	NPK	Yes	Autumn/spring	
R0-0701	AL-001-1985	Lönnstorp	1993	Clay loam	26x37	10	8	0.9-1	3	No	NPK	Yes	Autumn	
R0-8419	RX-001-1962	Lanna	1993	Clay	40x100	7	13.5	0.9-1	1-3	Yes	NPK	Sometimes	Autumn	Yes
R0-0647	RX-001-1997	Lanna	1998	Clay	40x42	6	13.5	0.9-1	3	Yes, organic	Cattle slurry	Sometimes	Autumn	
R0-0747	RX-002-1997	Lanna	1998	Clay	40x40	8	13.5	0.9-1	3-4	Yes, organic	Organic NP	Sometimes	Autumn	
R0-0047	N-001-1990	Mellby	1998	Sandy loam	30x30	8	7	0.9-1	4	Yes, organic	Cattle slurry	Sometimes	Autumn	Yes
R0-0447	N-001-1997	Mellby	1998	Sandy loam	30x30	7	7	0.9-1	3-4	Yes, organic	Organic NK	Sometimes	Autumn	
R0-0407	N-001-2020	Mellby	2020	Sandy loam	30x30	6	7	0.9-1	3	Yes	NPK, Cattle slurry	Sometimes	Autumn	

Table 10. Climate and location data R0 LTEs

Experiment serie	Experiment number	Site name	Latidude WGS84 Decimal	Longitude WGS84 Decimal	Nearest SMHI climate station	Altitude† (m)	Average yearly temperature† 1961-1990 (°C)	Average yearly temperature† 1991-2020 (°C)	Average yearly precipitation† 1961-1990 (mm)	Average yearly precipitation† 1991-2020 (mm)
R0-8403	N-026-1982	Mellby	56.4814	12.9859	Halmstad	7	7.2	8.4	783	850
R0-8410	RX-201-1992	Fotegården	58.4670	13.2379	Lidköping	61	6.2	7.4	563	678
R0-0701	AL-001-1985	Lönnstorp	55.6689	13.1028	Alnarp	10	7.7	8.8	567	612
R0-8419	RX-001-1962	Lanna	58.3461	13.1233	Lanna	73	6.1	7.3	558	584
R0-0647	RX-001-1997	Lanna	58.3461	13.1233	Lanna	73	6.1	7.3	558	584
R0-0747	RX-002-1997	Lanna	58.3461	13.1233	Lanna	73	6.1	7.3	558	584
R0-0047	N-001-1990	Mellby	56.4814	12.9859	Halmstad	7	7.2	8.4	783	850
R0-0447	N-001-1997	Mellby	56.4814	12.9859	Halmstad	7	7.2	8.4	783	850
R0-0407	N-001-2020	Mellby	56.4814	12.9859	Halmstad	7	7.2	8.4	783	850

†Of nearest SMHI climate station

Table 11. Overview of data available in databases (Microsoft Access)

	Type of data	Time
Drainage water	Flow data, primary and calculated	Day
	Water chemical data	Bi-weekly
	Nutrient leaching, loads and concentrations	Month, year
Cropping system	Field management and observations	Year
	Harvest, yields	Year
	Biomass, cover crops	Year
	Plant chemical data	Year
Soil	Mineral N data (0-90 cm)	At harvest, autumn, spring
	Basic chemical properties (0-90 cm)	Approx. 6 year intervals
Archive samples	Soil (basic soil mapping samples)	Approx. 6 year intervals
	Plant (mainly grains)	Year